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THE USE OF MULTI-STAGE ELECTRON-OPTICAL LIGHT AMPLIFIERS IN ASTROPHYSICS

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1. The solution of many problems of modern astrophysics demands a considerable increase in the sensitivity of the observational methods used. Of such problems it is sufficient to note spectral and photometric examinations of star novae, in whose atmospheres powerful nuclear processes sometimes occur over a period of not many minutes, and also the spectroscopy of the weakest extragalactic nebulae and, in particular, the problem of determining the red shift more accurately, which should yield an answer concerning the Universal metric.

The sensitivity of astrophysical apparatus can be increased, proceeding along two directions. The first is to increase the dimensions of telescopes. As is well known, the most powerful modern telescope is the five metre reflector of the Mount Palomar Observatory, and it is difficult to image that a telescope can be made in the next years with an aperture of another order. Therefore it is necessary in every possible way, to develop the second alternative, that is, a development of methods of detection in which the photon flux collected by the telescope is used more effectively.

One of such possibilities is to use a multi-stage electron-optical light amplifier, as described in (1). These devices have a large gain factor with a low level of characteristic noise, and they make it possible to detect the effect of a single electron(2)*.

We shall consider certain problems related to the use of electron optical light amplifiers in astrophysics. The resolving power of a multi-stage light amplifier is 10-20 lines/mm. This is approximately five times less than for a photoplate. Nevertheless, this latter circumstance is not of such great significance, in many cases, as it may appear at first sight. It is sufficient, in order to obtain an equivalent resolution in a given case, to merely increase the image scale (magnification) by five times[XX].

Let us estimate the gain in effectiveness obtained in utilizing the photon flux, compared with the usual photographic method. We shall proceed from the condition for obtaining a 10% accuracy in a photometric processing of the obtained material, which corresponds approximately to the accuracy for conventional photography under conditions of the maximum possible resolution. For this, in each image element of area 10^{-4} cm.^{2}, determined by the resolving power of the electron-optical light amplifier, it is necessary to accumulate the effect of a number of electrons such that the necessary photometric accuracy is attained, determined by statistics. This corresponds to the effect of 100 electrons. For an antimony-caesium photocathode, with a quantum efficiency of 0.1, this corresponds to 10^7 photons/cm.^{2}.

X Another method of detecting separate photo-electrons is electronic photography[(3)]. This method has an exceptionally high resolving power and, for a fine grain emulsion, sensitive to electrons, it is capable of obtaining very complete information about the object under investigation. However, the use of the electronic method of photography is associated with considerable difficulties: the necessity of using a demountable vacuum device, and the consequent necessity of changing photocathodes when the device is reloaded and the sensitive plates are introduced into the vacuum.

XX We note that, when the image scale (magnification) is increased still further, the same resolution can be attained here in practice, as for the electronic method of photography[3].

Comparison with the conventional method of photography should be performed for the minimum density possible, on a conventional photographic plate, to obtain a given accuracy of measurement. Nevertheless, it is sufficient, for an approximate comparison, to proceed from a density equal to unity, which is obtained under the action of $4 \cdot 10^{10}$ photons/cm.^{2} for modern high-sensitivity plates[4]. Hence, for the conditions considered, for the same image scale (magnification) in both cases, the efficiency of the electron-optical method is about $4 \cdot 10^3$ times greater than that for conventional photography. An increase in the image scale (magnification) on the photocathode of the light amplifier, necessary to equalize the effective resolving powers for both methods, reduces the sensitivity gain of the electron-optical method to 160 times compared with a conventional photoplate.

The comparative estimate for the sensitivity of the electron-optical method, performed in the given case with the assumption that the resolvable area on the photoplate is equal to $4 \cdot 10^{-4}$mm.^{2}, turns out to be very strict in respect of the lightamplifier. In actual fact, when a photogram is analysed photometrically, the resolvable area cannot be less than 10^{-2}mm.^{2}. Therefore the sensitivity of the light amplifier must be taken as a value in the order of 1000.

In general, the use of an electron-optical light amplifier cannot increase the penetrating power of a telescope, which is determined by the brightness of the night sky illumination[x-]. It is obviously necessary, for a full utilization of the penetrating power, that the effect due to the inherent noise of the light amplifier be significantly less than the sky background. It will be shown below that the light amplifier used satisfies this condition.

The large sensitivity of the light amplifier and the consequent reduction in exposure by hundreds of times (for equal effective resolving powers) must change the possibilities of astrophysical investigations in a significant way.

It reveals the way for a study of rapidly varying processes for the weakest objects (nova, non-stationary and variable stars) and makes it possible to raise, significantly, the efficiency of astrophysical instruments. The latter is especially important for large unique telescopes.

The reduction in exposure for astro-spectroscopy is of still greater significance. As a result of the unattainably large exposures required, if a conventional photographic method is to be used, the limit set by the night-sky illumination is not reached in practice. We can therefore say, in practice, that the use of a light amplifier for the field considered makes it possible to significantly increase the real penetrability of spectroscopic apparatus.

2. The ideas set out above are confirmed by the results of the first experiments performed by us at the Crimean Astrophysical Observatory of the Soviet Academy of Sciences. The observations were performed with a 500 mm. meniscus telescope, using a Maksutov system, with relative aperture F/13[5]. An electron-optical light amplifier was used, differing from that described in the paper (1) only in that its input stage had magnetic electron focussing. The light amplifier was supplied from a stabilized high potential source. Its resolving power was equal to 15 lines/mm. The antimony-caesium photocathode of the device had a sensitivity of 90 micro^{A}/lumen, and was at room temperature during the experiment. The image on the screen of the light amplifier was photographed using an objective with aperture F/1.5.

x The maximum penetrability for stars is attained in practice, with a scale for the turbulent disc of the star image equal to the resolvable element in the apparatus used.

The nature and level of the inherent moise of the light amplifier was investigated in the work (2). It was shown there that the dark current of the device consists of two components: mono-electronic and multi-electronic. The first component, governed by thermo-electric emission from the photocathode, is insignificantly small. Even at room temperature it is only about 3.10^{-18} a/cm.^{2} and cannot produce serious interference to observations. The multi-electron component of dark current is of considerably higher level. However, due to its strong dependence on the potential difference ΔVper stage (2), we can choose a mode of operation for the light amplifier ($\Delta V = 6KV$), for which the number of multi-electronic groups coming from 1 cm.^{2} of the photocathode is reduced to a few per second. The gain of the device here still remains sufficiently large so that the minimum signal can be photographed - the effect due to a single photo-electron from the first photocathode. Under these conditions, the noise at the negative electrode, governed by the inherent noise of the light amplifier, turns out to be at least two orders of magnitude less than the noise due to night sky illumination. This can be seen from Fig. 1. We notice that, as expected, the negative electrode noise is discreet in character, governed by the quantum properties of the photo-electric effect and the high gain of the device in the given case[x]. Thus, we see that the characteristic noise of the light amplifier can indeed be neglected compared with the sky background. In order to determine the gain in exposure time experimentally, the star field in Pleiades was photographed directly, as well as with the aid of the light amplifier. The mode of operation of the light amplifier was chosen to have somewhat greater sensitivity than that required to obtain a 10% photometric accuracy (see above). The resolving power for direct photography on the photoplate (without the light amplifier) was equal to about 20 lines/mm. The magnification for transfer of the image to the photocathode of the light amplifier was equal to 1:1. Under these conditions, an equal photographic effect was obtained in both cases for stars of 10th and 16th magnitudes respectively. Here, in the first case, the exposure was equal to four minutes, and in the second case one minute. Hence, the gain obtained in the time for photographing the same star was about 1000 times, which is in satisfactory agreement with the estimate obtained earlier.

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x The non-uniformity in the noise shown in Fig. 1b is due to the vignetting effect (at the edge of the field of view) and the non-uniform sensitivity of the light amplifier over the field (in the centre of the field of view). The latter can be apparently reduced to a few percent.

A photograph of the star field in Pleiades, obtained with the light amplifier, is shown in Fig. 2. Table 1 shows the star numbers according to the Hertzsprung catalogue[6] and their photographic magnitudes in accordance with the same catalogue.

Fig. 3 shows photographs that we have obtained, using the light amplifier, for two extra-galactic spiral nebulae. The structure of the nebulae can be seen quite well from the photographs. The results of a rough photometric analysis, without taking into account sky background and the non-uniform light amplifier sensitivity over its field, are shown in Fig. 4a, and the results of a microphotometer analysis of the noise, under the same conditions and in the same direction, are shown in Fig. 4b. The mean square noise fluctuation (in intensity) is about 5%.

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